UNDERSTANDING THE IMPACT OF TNC PRICING STRATEGIES ON THE PROSPECT OF TRANSIT AGENCY-TNC PARTNERSHIPS

FINAL PROJECT REPORT

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16. Abstract

Transportation network company (TNC) trip prices have fluctuated significantly higher than they were two years ago, causing concerns about existing and planned partnerships between public transit agencies and private mobility service providers. This project explored three scenarios of future TNC price changes: (1) price trend extension based on forecasting models, (2) price increases in response to local policy changes, and (3) TNC/taxi price convergence due to increased competition. We then assessed the impacts of the price changes from each scenario on the prospect of transit agency-TNC partnerships, using a planned same-day-service (SDS) paratransit pilot project in the Seattle region as a case study. For the first scenario, we employed two time-series models, namely ARIMA and PROPHET, to forecast price changes within the next three years (October 2022- October 2025) based on publicly available TNC trip data from Chicago. The results showed that TNCs' daily average price would reach up to $3.23 per mile, increasing by 40 percent from 2019 average rates. For the second scenario, we tracked significant policies that directly affected TNC prices in Seattle and incorporated reported price increases. The resulting estimations indicated that TNC prices would increase by an extra 25 percent in response to changes in the local minimum wage law. For the third scenario, we used publicly available taxi trip data from Chicago and forecasted future taxi prices by estimating time-series models comparable to those for TNC prices. The analysis suggested that because of increased competition, TNC and taxi prices could converge, and the average TNC fare per mile could increase by another 50 percent of the forecasted price if TNC and taxi prices become similar in the upcoming three years.

By applying the three scenarios to the case of SDS in Seattle and considering a pre-determined $40 subsidy per TNC trip, our results showed that in the first scenario, the rate of trip diversion from ADA paratransit to TNCs, initially estimated at 70 percent based on TNC prices in 2019, would drop to 55 percent if the price trend extended over the upcoming three years. In the second scenario, the divertible trip rate could drop further to 51 percent to respond to local policy changes in Seattle. Finally, the divertible trip rate could be as low as 45 percent if TNC and taxi prices converge. This significant decrease in divertible trip rates could negatively affect the expected cost-effectiveness of transit agency-TNC partnerships. Although such partnerships could still provide many benefits, transportation planners and policymakers should carefully examine the significantly higher costs likely resulting from TNC business models and changing market and policy environments.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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LIST OF ABBREVIATIONS

ADA	Americans with Disabilities Act
ARIMA	Auto-Regressive Integrated Moving Average
COVID-19	Coronavirus disease 2019
ICT	Information and communication technology
KCM	King County Metro
MAPE	Mean absolute percentage error
RMSE	Root-mean-square error
SDS	Same-day-service
TNC	Transportation network company

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EXECUTIVE SUMMARY

In the last few years, with the rapid development of mobile information and communication technology (ICT), app-based, on-demand mobility services have become the most rapidly growing form of urban transportation. These new mobility services, including ride-sourcing, have motivated many transit agencies to partner with transportation network companies (TNCs) in providing services to achieve some critical goals for transportation (e.g., providing first- and last-mile connection and ADA paratransit services). However, TNC pricing strategies and tactics pose major challenges to these goals. Concerns about rising TNC prices have recently heightened as the COVID-19 pandemic recedes and more people return to using TNC services. This research project explored three TNC price change scenarios and their respective impacts on transit agency-TNC partnerships.

Problem Statement

TNC prices have increased by over 40 percent since the COVID-19 pandemic outbreak. Although these startling fare increases have not been explicitly justified by TNCs, they have been attributed to the recovery of demand but not of drivers, allowing TNCs to price their rides at higher rates and use surge pricing to lure drivers to high-demand areas. Such price increases threaten the cost-effectiveness and sustainability of transit agency-TNC partnerships, making it difficult for agencies to design or maintain them. Therefore, research is needed to investigate TNC price changes and predict their long-term impacts on existing and planned partnerships between public transit agencies and private mobility service providers.

Methods

This project developed three scenarios to explore the impacts of TNC price changes on prospective and existing transit agency-TNC partnerships. The first TNC price change scenario involved a price trend extension developed with forecasting models. We employed two time-series models, ARIMA and PROPHET, to forecast price changes within the next three years (October 2022 to October 2025) using publicly available Chicago TNC trip data.

The second scenario investigated TNC price increases in response to local policy changes. This involved, first, tracking significant policy changes that have been affecting TNC prices in Seattle and corresponding price changes, and second, incorporating these additional price increases into the total forecasted price.

The third scenario involved a comparison of taxi and TNC trip prices. We used publicly available taxi trip data from Chicago to compare changes in taxi prices with TNC prices and to forecast future taxi prices using similar time-series models. Our analysis suggested that because of increased competition, TNC and taxi prices are converging, which could cause TNC trip prices to be similar to the prices of taxi trips in coming years.

Finally, we used the same-day-service paratransit pilot project in the Seattle region as a case study to assess the impacts of all the price change scenarios on the potential rate of trip diversion from paratransit to TNCs as a key metric for evaluating the cost-effectiveness of prospective transit agency-TNC partnerships.

Results

By applying the three scenarios to the case of same day service in Seattle and considering a pre-determined $40 subsidy per TNC trip, our results showed that in the first scenario, the rate for diversion of trips from ADA paratransit to TNCs, initially estimated at 70 percent based on TNC prices in 2019, would drop to 55 percent if the price trend extended over the upcoming three years. In the second scenario, the divertible trip rate could drop further to 51 percent to respond to local policy changes in Seattle. Finally, the divertible trip rate could be as low as 45 percent if TNC and taxi prices converged.

Such price changes were found to significantly decrease the percentage of divertible trips previously expected. Although partnerships with TNCs could provide many benefits, transportation planners and policymakers should carefully examine significant barriers that will likely result from TNC business models and the political environment.

CHAPTER 1. INTRODUCTION

In the last decade, with the rapid development of mobile information and communication technology (ICT), app-based, on-demand mobility services have become the most rapidly growing form of urban transportation [1-3]. These new mobility services, especially ride-hailing provided by transportation network companies (TNCs), while presenting a severe challenge to the current operations of public transportation, are simultaneously creating many exciting opportunities for building new partnerships between transit agencies and private providers [4-7]. Through a model of complementary operations, transit agencies' motivation to partner with TNCs in providing services is to achieve some critical goals for transportation, such as improving mobility by filling service gaps (e.g., providing first- and last-mile connections), increasing options for people with disabilities and residents of less accessible areas, and reducing costs and vehicle miles traveled (VMT) [8-13, 7].

Because TNCs' business model and operational norms broadly differ from those of other operators, transit agencies have responded with two standard partnership designs: subsidized TNC trips or marketing partnerships, with most partnerships involving a direct transaction between transit agencies and TNCs [10]. A recent transit agency survey conducted by Nelson\Nygaard showed that over 78 percent of transit agency-TNC partnerships include the exchange of funds in the form of subsidized trips, with more than 50 percent of these partnerships targeting people with disabilities [10]. By partnering with TNCs, transit agencies can supplement their conventional paratransit with a demand-driven service, potentially reducing their overall costs while providing service improvements and expansion.

However, TNC pricing strategies pose many challenges for these expected cost savings. Concerns about TNC prices increased during the COVID-19 pandemic, as the rising vaccination rate in the United States resulted in more people returning to TNC services, which many saw as a safer and more reliable alternative to public transit. Rakuten Intelligence research found that the cost of a TNC ride in the U.S. increased by 37 percent in March 2021 and by 40 percent in April 2021 in comparison to the previous year [14]. These price increases put the cost-effectiveness and sustainability of transit agency-TNC partnerships at stake, making it difficult for agencies to design or maintain them. As the demand for transportation services in the U.S. gradually returns to normal, it is essential to investigate the impacts of TNC pricing strategies on ride-hailing service fares and to understand the implications for transit agencies.

This research aimed to assess the impacts of TNC price changes and to fill major research gaps. First, few studies have analyzed the implications of TNCs' changing pricing strategies. While some studies have explored the potential for TNCs to help public transit agencies achieve cost savings, they have usually overlooked the long-term impacts of TNC pricing strategies in response to the changing market and policy environment, which likely will lead to price increases [15]. Second, few studies have estimated the cost-effectiveness of transit agency-TNC partnerships under different pricing scenarios. Because most transit agencies have designed their partnerships with TNCs based on a subsidy that covers a certain fare, mileage per trip, or a capped number of trips, recent price increases require adjustments and revaluation of partnership design specifics and potentials. Current studies that have analyzed the cost-effectiveness of transit agency-TNC partnerships have often relied on pre-existing and generalized TNC prices [10, 16-19]; recent changes in TNC service fares have yet to be seriously examined.

This study employed Chicago ride-hailing trip data (2018 to 2022) and taxi trips data (2013 to 2022) to examine TNC price changes and then used data from Access paratransit service trips operated by King County Metro (KCM), the primary transit service provider in the Seattle region, to explore the impacts of TNC price changes on transit agency-TNC partnerships.

In an effort to inform transit agencies about planning partnerships with TNCs, we used detailed ride-hailing and paratransit trip data to explore different TNC pricing scenarios and their impacts on trip diversion rates between conventional Access paratransit and service operated by a TNC to answer the following questions:

1. What will likely be the changes in TNC service fares in the coming years? How do those compare to likely changes in taxi prices?
2. What factors related to TNC business models and market and policy environments contribute to TNC trip price changes?
3. How will TNC price changes affect the prospect of building and sustaining partnerships between transit agencies and TNCs?

CHAPTER 2. LITERATURE REVIEW

It is evident that transportation network companies (TNCs) such as Uber and Lyft have tremendously shifted urban mobility and affected travel behavior for many users in the U.S. and worldwide. Partnering with TNCs has emerged as a promising, cost-effective alternative for many transportation agencies in the U.S., which recognize the ability of TNCs to provide specific types of services with demonstrated flexibility and innovation in improving the user experience [10]. In 2019, the Transportation Research Board (TRB) published a survey of 38 transit agencies showing that 57 percent of transit agencies' partnerships with TNCs targeted people with disabilities, followed by people connecting to transit (first mile/last mile) or traveling in lower-density environments. For providers of paratransit services mandated by the Americans with Disabilities Act (ADA), such partnerships look promising because of the potential cost savings, allowing transit agencies to increase service quality and flexibility in comparison to conventional transit service [16, 19]. However, TNC pricing strategies and business models have experienced instability in regard to price fluctuations, policy changes, and legal challenges. Hence, transit agencies need to consider the dynamics of TNC pricing and future changes and to carefully analyze their impacts on the prospects of their partnerships and the effectiveness of planned pilot projects.

2.1. TNC Economics

TNCs are digital marketplaces that mediate taxi-like, on-demand transportation services by connecting independent drivers to riders through advanced digital platforms [20, 21]. Since their first entry into the market in 2010, the speed of adoption and expansion of ride-hailing services offered by TNCs has been impressive. Today, Uber alone operates in more than 80 countries around the world, and many countries have cloned Uber's model with minor modifications to meet local regulations and laws. Although TNCs provide services similar to those of taxis, the key success to their expansion lies in their business models and operational innovation. Many researchers have noted that TNCs (e.g., Uber) established a business model involving venture capital financing with an aggressive strategy to disrupt the established vehicle-for-hire industry (e.g., taxis) by introducing a new digital marketplace [21]. This organizational model established a unique work arrangement in which drivers are self-employed and operate services using their own vehicles, which many consider a form of hyper-precariousness [22, 23], exhibiting characteristics of platform-mediated, in-person service work known as gig labor. However, TNCs also rely on more typical work types, e.g., "venture labor" performed by high-paid employees who manage and develop the digital infrastructures of TNCs and their activities [24, 25].

This business model has faced legal backlash worldwide, even being found to be disruptive and illegal in many European countries [26]. However, the shift caused by TNCs is much less radical than assumed, as digital technology moves traditionally mediated taxi self-employment to a digital platform [21]. Although the platform technology allows for various organizational models, through fierce competition a few dominant service providers have implemented work types that foster the described working conditions [27]. In contrast to the disruption induced by tech start-ups with venture capital backing, TNCs have generally shown a pattern of absorption by incumbents to expand their business and superimpose themselves on emerging markets [28].

2.2. TNCs vs. Taxis

Although both TNCs and taxis provide similar services, TNCs' business models allow them to control their service pricing and the information flow between drivers and riders. In addition, TNCs are based on market deregulation and benefit from many preemptions and laws tailored to their business. On the other hand, the heavily regulated taxi companies have to conform to many regulations regarding their prices and driver hiring procedures, which increase their operational costs, resulting in higher trip prices. Although TNCs' business models increase their competitive advantage in comparison to that of taxis, they face serious profitability challenges [15]. This is mainly a result of increased competition due to the ease of market entry, which allows TNCs to lower their trip prices and sometimes charge below-cost rates to price competitors out of the market. However, the TNC model involves fixed costs that are challenging to recover with current pricing strategies. TNCs have sought to overcome these challenges by expanding their market through mergers, acquisitions, and service diversification (e.g., Uber acquired the Jump bike-sharing service for $200 million in 2018). The main goal for TNCs' growth is market domination [29, 30].

Moreover, the overall decline in demand for taxis and other vehicle-for-hire services following the increased popularity of TNCs, shown by Bagchi (2018), indicates that TNCs are offering more value for their prices [31]. The increased competition means that in order for traditional taxis to survive, they must adapt to a more technologically advanced model. However, taxi companies must conform to regulations that increase their costs and prices. TNCs mostly frame their business as a different industry called "ridesharing" so they can avoid taxi-like regulations and legal issues. Despite their efforts, TNCs generally have been under immense regulatory pressure since their entrance into the transportation market. Recently, more policies have been implemented to limit the number of drivers on the road, working hours per driver, and minimum charges and wages for TNC drivers [29]. Recent studies showed that the policies related to limiting working hours and requiring more regulatory oversight benefit taxi firms, which were previously regulated and did not incur a cost from the new regulations on TNCs [15, 21, 30]. A recent study on the New York for-hire market showed that regulations imposed on TNCs increased taxi rides and revenues [30], which further proved that the increasing costs of TNCs increase the ridership of traditional taxis.

2.3. TNC Profitability

Although TNCs enjoyed massive revenues in their first seven years, Crunchbase news reported on Uber's 2017 financials and concluded that it lost over $1 billion U.S. [32]. The article attributed the loss to the fact that the majority of Uber's revenue goes to drivers, who are paid over 80 percent of the collected fares in the form of driver pay and discounts to riders, and the remaining 20 percent was not sufficient to cover the cost of revenue and other operating expenses. Similar losses were also reported in 2018, as Uber and other TNCs have pursued to charge low rates—also referred to as predatory pricing—and offered discounts to achieve remarkable growth to increase their market share or even dominate the TNC market [15]. Amid this race for market domination, such pricing strategies put the long-term profitability of TNCs in jeopardy, as many riders do not realize that their trips are heavily subsidized; this makes it challenging for TNCs to increase their rates as they would likely lose riders and, therefore, drivers. Although TNCs have obtained a significant market share, reaching more than ten times that of taxis in 2017 [15], their share has been mainly sustained by the fierce price war. For instance, Uber's market share fell from 84 percent to 77 percent in 2017 alone as its rival Lyft started to accelerate [33].

In addition to financial challenges, the strive for market dominance by large TNCs has also been challenged by their organizational work type, mainly gig workers who can easily switch between different TNC apps. As Lyft and Uber have battled for market share, both companies have raced to the bottom by spending vast amounts of money on promotional discounts for riders [15, 33]. At first, it seems implausible to question the business plan of such wildly successful TNCs. However, a growing number of analysts have questioned whether TNCs can ever become profitable, given their pricing strategies that do not generate enough revenue to compensate drivers or profit their shareholders sufficiently. By pricing their services at least 30 percent below taxi fares and retaining 20 percent of revenues, TNCs squeeze the revenues available to compensate drivers, who are essential to providing both the labor and resources to serve riders [34]. Currently, there is nothing in TNCs' business models that promise a reduction in costs for ride-hailing services, nor are there inherent economies of scale that would lower unit operating costs with continued growth [15, 33,34].

2.4. Recent Changes in the TNC Market

The COVID-19 outbreak had a profound effect on the ride-sharing market, especially on TNCs as the demand for the service plummeted in large metropolitan areas because of lockdowns and safety concerns [35-38],. For instance, during the first three months of the outbreak, Uber announced that trips declined by 60 to 70 percent in Seattle and 77 percent in London and Paris [35]. In addition to the decrease in demand, TNC supply saw a similar crash, as the number of active drivers accepting trips declined by 71.6 percent in the same period [36]. The loss of drivers, albeit a natural result of the reduced demand, can also be attributed to the reluctance of new drivers to join TNC apps during the pandemic and the rising competition among food delivery apps, which were generally safer and in high demand, e.g., UberEats [36, 37]. In 2021, as the pandemic started to recede, the reduction in drivers reportedly forced TNCs to raise their trip fare rates to lure drivers back and safeguard the service supply. Nevertheless, many drivers have complained about not getting a fair share of the increased prices, and some even claimed that their pay "has not been raised at all." [37]. Also, with significantly increased fares, there have not been sufficient raises to compensate for increased costs of living and rising gas prices. Recent reports and surveys have shown that nearly half of TNC drivers have stopped driving or reduced their driving hours, despite fuel surcharges and increased fares [38]. Such effects, coupled with a recovering demand in a post-pandemic world, continue to raise TNC fares to unprecedented levels at the time of this writing. The soaring TNC prices, coupled with inflation, create many challenges for passengers and exacerbate the legal backlash that TNCs face in many countries. This continuous struggle to balance supply, demand, and prices in a changing global economy makes it essential to investigate the likely changes in TNC service fares in the coming years and the implications of TNC price changes for partnerships between transit agencies and TNCs.

4.7. Data for Understanding TNC Price Changes

TNCs hold a firm grip over their operational data, which adds another layer of complexity to the battle to regulate drivers' payments, background checks, and trip prices [39]. Although "sunshine laws" require that specific information obtained by governments be publicly accessible, there has been an ongoing struggle to obtain TNC data by the public or city transportation planners [40, 10]. TNCs have always been reluctant to share their operational and revenue data that they classify as "trade secrets" for reasons of privacy, public records requests, and competition concerns, and in many instances, they have succeeded in persuading city councils to include privacy provisions (e.g., Seattle Ordinance 124524) [15].

The lack of systematically collected price data makes it challenging to estimate future changes and to fully understand the potential of transit agency-TNC partnerships in providing cost-effective mobility alternatives. However, the City of Chicago now publishes trip-level data for every ride-hail trip since November 1, 2018. Chicago is not the first major U.S. city to make ride-hailing trip data publicly available—New York has published Uber and Lyft data since 2014—but the Chicago dataset includes additional variables, most notably fare amounts, that provide new insights into the ride-hailing landscape

CHAPTER 3. METHODOLOGY

This study adopted a multi-step methodological framework to examine and forecast TNC prices in the coming years and to assess the impacts of TNC price changes on transit agency-TNC partnerships. We employed time-series modeling techniques to forecast future TNC trip prices using publicly available trip data. We then utilized a transit agency-TNC partnership case to illustrate the implications of predicted price changes on such partnerships. Table 3.1 summarizes the different scenarios in which TNC prices could likely change in the coming years.

Table 3.1 TNC Price Change Scenarios

TNC Price Change Scenario	Analytical Method	Price Change Measure
(1) Price Trend Extension	• Time series forecasting to predict TNC fares • Model parameters tuning to find the best fit	• Forecast average USD/Mile in 2022-2023 based on price trend • Measure percent change in forecasted price compared to 2019
(2) Price Increase in Response to Local Policy Changes	• Track the impact of local regulations and policy changes on prices (e.g., minimum wage ordinance)	• Use publicly available estimates of percent change in TNC price • Combine with forecasted percent change in scenario (1)
(3) TNC/Taxi Price Convergence due to Increased Competition	• Time series forecasting to predict taxi fares • Price convergence in the for-hire market (taxis)	• Use forecasted taxi data to measure percent difference between taxi and TNC price

3.1. Price Trend Extension

3.1.1. Trips Data

The City of Chicago has published trip-level data for every TNC trip since November 1, 2018. Although many other cities in the U.S. have made TNC data publicly available or accessible, to our best knowledge, the Chicago dataset is the only one that includes trip fare variables. As we wrote this report in October 2022, the dataset included approximately 263 million trip records (rows) and 21 features (columns) for trips dated from November 1, 2018, through October 1, 2022. The features of these data included Trip ID, Trip Start Timestamp (rounded to the nearest 15 minutes), Trip End Timestamp (rounded to the nearest 15 minutes), Trip Seconds, Trip Miles, Pick-Up Census Tract, Drop-Off Census Tract, Pick-Up Community Area, Drop-Off Community Area, Trip Fare, Tip, Additional Charges, Total Trip Fare, Shared Trip Authorized, Trips Pooled, Pick-Up Centroid Latitude, Pick-Up Centroid Longitude, Pick-Up Centroid Location, Drop-Off Centroid Latitude, Drop-Off Centroid Longitude, Drop-Off Centroid Location.

As the dataset is too large to be processed without a supercomputer, we generated a random sample of 2 million trips from November 2018 to June 2022 with valid pick-up and drop-down area information. To explore the data, we processed the features to extract date information from the timestamp. We created new variables, including each trip's average fare per mile (excluding tips and additional charges, mainly taxes).

Similarly, the City of Chicago published a taxi trips dataset from 2013 to the present in its role as a regulatory agency. To protect privacy but allow for aggregate analyses, the Taxi ID is consistent for any given taxi medallion number but does not show the number, and times are rounded to the nearest 15 minutes. Because of the data reporting process, not all but most trips are reported. Taxicabs in Chicago, Illinois, are operated by private companies and licensed by the city. About 7,000 licensed cabs operate within the city limits.

3.1.2. Forecasting Models

We used forecasting models to ascertain the trend and the seasonality in TNC price time-series data, which could generate valuable insights into and predictions of future TNC price changes. The trend represented the general direction in which the time series of TNC prices was headed. Seasonality was a recurring pattern in the data (e.g., daily, weekly, or yearly). What could not be explained by the seasonality and trend was the random fluctuation in price.

To determine approximate future TNC price changes based on previous trends, we intended to forecast the time series of daily average fare per mile in Chicago based on data recorded from November 1, 2018, to October 1, 2022, and to display the patterns of the time series of daily average fare per mile for one year ahead. We applied two different approaches that could produce future results. They were the Auto-Regressive Integrated Moving Average (ARIMA) model and the forecasting procedure PROPHET. ARIMA models are popular and have been applied in many fields for decades, while PROPHET can be considered a new approach (released in 2017) that is renowned for its usability and modeling capacity.

3.1.3. Data Preparation

PROPHET and ARIMA have default timestamps, so conversion into Date and Time was necessary for forecasting. To account for seasonal events that would impact the price, we added dummy variables for selected holidays in the U.S.: Christmas, New Year's, Thanksgiving, Easter, and Independence Day. External regressors were included to explain the remaining price variations. We identified climate, gas prices, and the COVID-19 lockdown as important regressors in the case of TNC prices. Hence, we combined the trip data with Chicago weather data, including average temperature in degrees, snow depth (inches), and precipitation (inches) obtained from the National Center for Environmental Information and average monthly gas prices (USD/gallon) in Chicago obtained from the Energy Information Administration. Lastly, we added a dummy variable for theCOVID-19 lockdown, which severely impacted TNC and other transportation services from March 20, 2020, to July 25, 2020.

3.1.4. Forecasting with ARIMA

The AR in ARIMA stands for autoregressive, represented by the *p* in equation (2). It refers to the number of y(t) lags to be used as the predictor. A pure AR model would be one in which y(t) depended only on its past values (y(t-1), y(t-2),…). A typical representation of an autoregressive model of order p can be written as

$$\boldsymbol{y(t) = c + a1y(t-1) + a2y(t-2) + a3y(t-3) \ldots\ldots + et} \quad \textbf{(1)}$$

where εt represents white noise, i.e., random fluctuation. Unlike the AR model, which uses past values, the moving average (MA) model depends only on past forecast errors, represented by *q* in equation (2). Finally, the I in ARIMA stands for Integrated, which is used to reflect the amount of differencing needed to make the data stationary before the AR and MA parts of the model are estimated. In this context, differencing is the reverse of integration. The formula for ARIMA could be represented as

$$\boldsymbol{y(t) = \mu + \phi 1y(t-1) + \cdots + \phi p\, y(t-p) - \theta 1\, e(t-1) - \cdots - \theta q\, e(t-q)} \quad \textbf{(2)}$$

where y(t) represents the series of differences as it may have been differenced multiple times, and the right side of the formula includes both lagged values of the AR model and lagged errors from the MA model. Here (θ) represents the moving average parameters with a negative sign[1]. In the case of seasonal ARIMA, known as SARIMA, the data are split into two parts, seasonal and non-seasonal, with the seasonal part optimized similarly to that in ARIMA. SARIMAX is a SARIMA model that adds external regressors to explain variations caused by non-seasonal factors such as weather, the lockdown, marketing campaigns, and discounts.

To identify the appropriate ARIMA model for Y, we used the Auto ARIMA function in R, which returns the best ARIMA model according to AIC or BIC values. We used the data from

[1] In the R programming language, ARIMA parameters have plus signs, and are denoted by AR(1), AR(2), …, and MA(1), MA(2), … etc.

November 28, 2018, through October 1, 2022, for data training. We forecasted the last five months of the data (April 1, 2022, to October 1, 2022) to estimate the model accuracy, including the external variables and holidays as exogenous regressors. The Auto ARIMA model resulted in regression with SARIMAX with the following parameters:

p: order of the autoregressive in the non-seasonal part

d: degree of first differencing in the non-seasonal part

q: order of the moving average in the non-seasonal part

P: order of the autoregressive in the seasonal part

D: degree of first differencing in the seasonal part

Q: order of the moving average in the seasonal part.

3.1.5. Forecasting with PROPHET

PROPHET is a procedure for forecasting time series data created by Facebook's Core Data Science team. It aims to provide an easy-to-use tool for modeling time series data. PROPHET works best with time series data with strong seasonality and extensive historical data, and it is robust to outliers and shifts in the trend. It also has built-in cross-validation for parameter tuning. Unlike ARIMA, PROPHET explores the impacts of dynamic holidays, such as Christmas, separately from regressors, with the ability to explore a window of their impact in near dates, and it is capable of dealing with non-linear regressors.

$$\boldsymbol{y(t) = c(t) + s(t) + h(t) + x(t) + e} \qquad \textbf{(3)}$$

c(t): trend

s(t): seasonality

h(t): holidays: PROPHET enables the exploration of neighboring days of holidays x(t): external regressor: non-recurrent variables (events that are not on the same dates every year) or disruptive events like the COVID-19 pandemic

E: error.

We used data from November 28, 2018, through October 1, 2022, for data training, and we forecasted the last five months of the data (April 1, 2022 to October 1, 2022) to estimate the model accuracy. We included the list of exogenous variables as external regressors and the holidays, and we explored two neighboring days before and after each holiday. We applied PROPHET's built-in cross-validation, which conducted several test sets to tune the model parameters, increased the model's accuracy for different seasonality, and reinforced the validation of the model by testing it in different scenarios. We ran 185 forecasts, which involved different parameter values, and used the resulting parameters from the most accurate model by measuring forecast errors using historical data and comparing the forecasted values to the actual values. We obtained the following parameters for the model, which we used to predict future prices within the next three years.

Yearly seasonality = TRUE

Weekly seasonality = TRUE

Daily seasonality = FALSE

Seasonality mode = 'additive'

Seasonality prior scale = 5

Holidays prior scale = 5

Changepoint prior scale = 0.1

3.2. Price Increase in Response to Local Policy Changes

The first scenario forecasted prices for three years (October 2022 to October 2025) based on TNC trip data from Chicago. However, many legal and political factors affect TNC prices differently. Hence, when adapted to other cities, price forecasts should incorporate local policies and their additional impacts on the forecasted price. In this study, we used price forecasts based on Chicago TNC prices to assess the implications of such changes on a Seattle-based partnership case. Therefore, in addition to considering a similar percentage change in TNC prices in Seattle, we had to consider local policies that affect only Seattle's TNC prices. For instance, the Seattle City Council passed legislation (effective in 2021) that set the minimum wage for TNC drivers at $17 per hour. In response, TNCs such as Uber and Lyft had to raise trip prices. Initial estimates indicated that TNC prices increased by as much as 25 percent and could reach as much as 50 percent [38]. In addition, a new ordinance related to app-based worker labor standards (effective starting 2024) establishes a similar compensation scheme for app-based workers (gig workers), amending Sections 3.02.125, 3.15.000, and 6.208.020 of the Seattle Municipal Code and adding a new Title 8 and Chapter 8.37 to the Seattle Municipal Code. In this scenario, we tracked reports and publications that estimated the percentage increase in TNC prices to comply with regulations and policy changes.

3.3. TNC/Taxi Price Convergence due to Increased Competition

With ongoing regulatory processes and legal pressures on TNCs, their trip prices may continue fluctuating and mainly increasing to correspond to new laws and ordinances (e.g., minimum wage requirements and limitations on drivers' work hours). In return, higher trip prices will decrease the competitive advantage of TNCs and increase competition between TNCs and taxis. As long as taxis are as regulated as they are today, they will continue to bear the total weight of the regulatory burden, whether or not TNCs are regulated. Regulating TNCs could only increase their operating cost and thus raise their prices, making taxi fares less undesirable to riders. A continuation of these policies, accompanied by taxis' adaptation of technologically advanced capabilities, will burden TNC consumers, who might shift away from TNCs or become indifferent to which mode they choose. Under the assumption of increased competition between taxis and TNCs, and given the lack of profitability of TNCs, it is conceivable that TNCs' average fare per mile will become equivalent to that of taxis.

Chicago has published trip-level data for every taxi trip since 2013. We used the taxi fare data to estimate the average daily fare per mile for taxis. We used taxi data to compare the difference between their trip prices and those of TNCs at different times. We also used taxi trip data to forecast future changes. Our observations were that taxi fares have been declining and approaching a potential convergence with TNC prices, which is explained in more detail in the next section. In this scenario, we used forecasted future taxi prices to estimate changes in TNC pricing in the face of increased competition.

3.4. Assessing Likely Impacts on Transit Agency-TNC Partnerships

We used a case study of a planned transit agency-TNC partnership to assess the impacts of TNC price changes. The case involved subcontracting some paratransit services currently operated by King County Metro through its Access paratransit program to TNCs—referred to here as same-day-service (SDS). We used the change in cost-effectiveness of the transit agency-TNC partnership, measured here by the change in the rate of trip diversion from the Access program to SDS, as the key metric of the impact. For this purpose, we use a fixed subsidy amount that King County Metro pre-determined in 2019, along with initial trip diversion estimates, to measure the change in trip diversion rate under different TNC price change scenarios. Specifically, King County Metro decided on a maximum of $40 subsidy per trip for SDS service offered by TNCs, which we used to estimate divertible trips under each TNC price scenario and to compare the results across the scenarios.

CHAPTER 4. RESULTS

4.1. Scenario (1): Price Trend Extension

4.1.1 Data Exploration

Exploring the changes in daily average fare per mile for both taxi data (November 2013 to October 2022) and TNC data (November 2018 to October 2022) showed that both services had higher fluctuations in prices during the pandemic, with taxi prices peaking during July 2020 and TNC prices peaking at the beginning of 2021. Figure 4.1 indicates that taxi prices showed an overall downward trend following the first few months of the pandemic, with most of the fares falling beneath the all-time average fare of $5 per mile. On the other hand, Figure 4.2 shows that TNC prices were mostly above average after the pandemic outbreak.

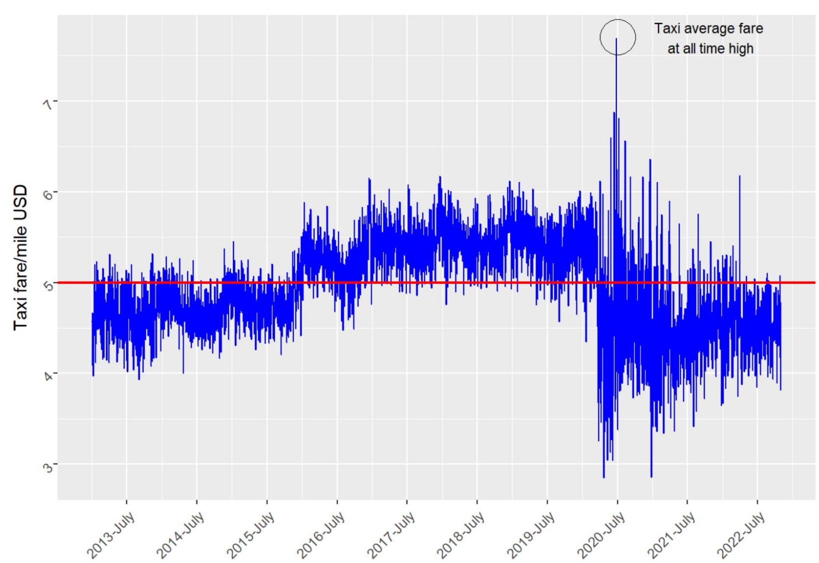

Figure 4.1 Daily Average Taxi Fares (USD/Mile)

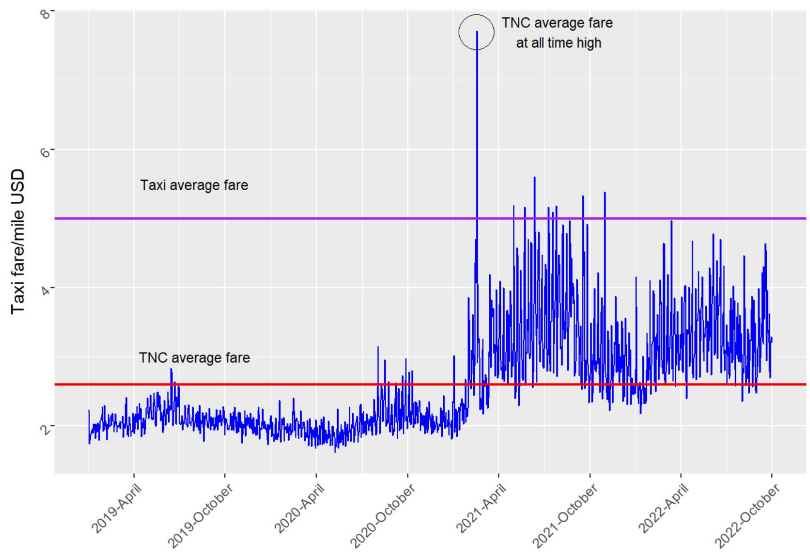

Figure 4.2 Daily Average TNC Fares (USD/Mile)

The yearly seasonality graphs for average daily TNC prices, shown in Figure 4.3, and for taxi prices, shown in Figure 4.4, reflect some important differences between the two services. Although both services experienced fluctuations in their prices during the pandemic, TNC prices continued to fluctuate highly and rose above pre-pandemic prices in 2019, whereas taxi prices started to settle at less than pre-pandemic prices starting in 2021.

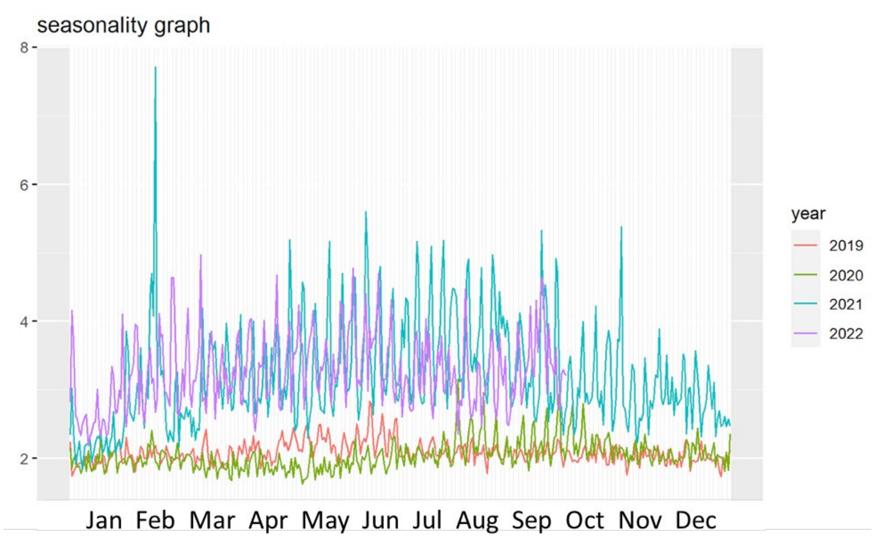

Figure 4.3 Yearly Seasonality Graph of TNC Fares (USD/Mile)

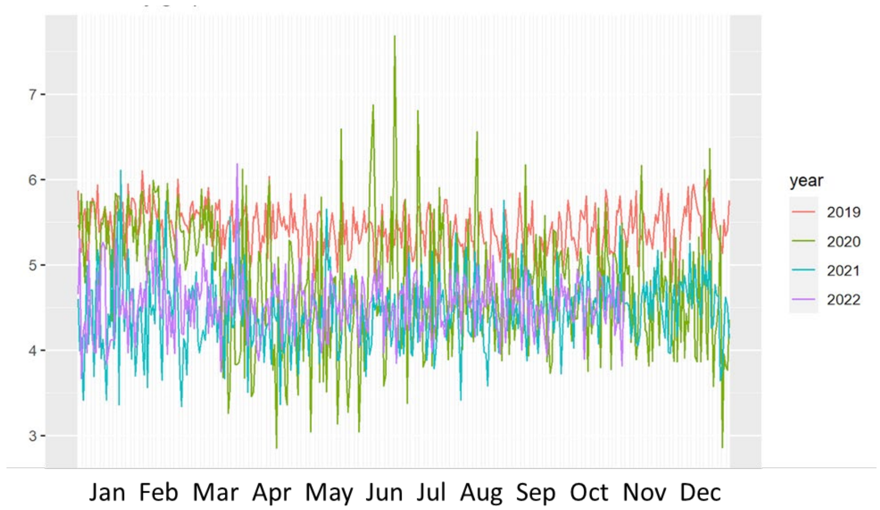

Figure 4.4 Yearly Seasonality Graph of Taxi Fares (USD/Mile)

4.1.2 Forecasting TNC Prices with ARIMA

Using both the ARIMA and PROPHET models, we forecasted the average taxi fare per mile within the next three years (October 1, 2022, to October 1, 2025). We summarized TNC trip data into daily average fare per mile and forecasted the daily average fare per mile for TNCs for the next three years. We used a SARIMAX model, which split the data into two parts, seasonal and non-seasonal; the latter gave us the ability to understand the effects of exogenous regressors that seasonality would not explain. We used the auto ARIMA function in R to optimize the model parameters with the Akaike information criterion (AIC) and Bayesian information criterion (BIC). The optimized model had the following parameters:

The order of the time series (p,d,q):

p = 2: Auto Regression with two lags

d = 0: No differencing

q = 1 Moving average with one lag for error.

The order of the seasonal component of the time series (P,D,Q):

P = 0: Auto Regression with zero lags

D = 1: One differencing

Q = 1: Moving average with one lag.

We trained the model by using the last five months of TNC prices (May 2022 to October 2022) and included seasonal holidays (Christmas, Easter, Thanksgiving, New Year's Eve (NYE), and Independence Day) and external factors (average temperature (TAVG), precipitation (PRCP), snow levels, and average daily gas prices) as exogenous regressors. The results are shown in tables 4.2 and 4.3.

Table 4.2 ARIMA Parameters

	ma1	**ma2**	**ma3**	**sar1**
coeff	1.1652	-0.2093	-0.8254	-0.8366
s.e	0.1061	0.0697	0.0922	0.0238

Table 4.3 ARIMA Results – Exogenous Variables

	Christmas	**Easter**	**Thanksgiving**	**NYE**	**Independence**	**Lockdown**	**PRCP**	**snow**	**TAVG**	**gas**
Unit	**binary**	**binary**	**binary**	**binary**	**binary**	**binary**	**inches**	**inches**	**degrees**	**USD/gallon**
coeff	-0.2030	0.1443	0.2356	0.5424	-0.0853	-0.0854	0.0581	0.0284	-0.0008	0.1911
s.e	0.1696	0.1474	0.1685	0.1511	0.1687	0.1270	0.0297	0.0158	0.0014	0.1884

For the exogenous regressors shown in Table 4.3, the model indicated that NYE and PRCP had a statistically significant positive correlation with average TNC fare. The SARIMAX model showed high accuracy, with a root-mean-square error (RMSE) of 0.448 and a mean absolute percentage error (MAPE) of 10.277. We used this model to predict future TNC prices for the next three years, as illustrated in Figure 4.5.

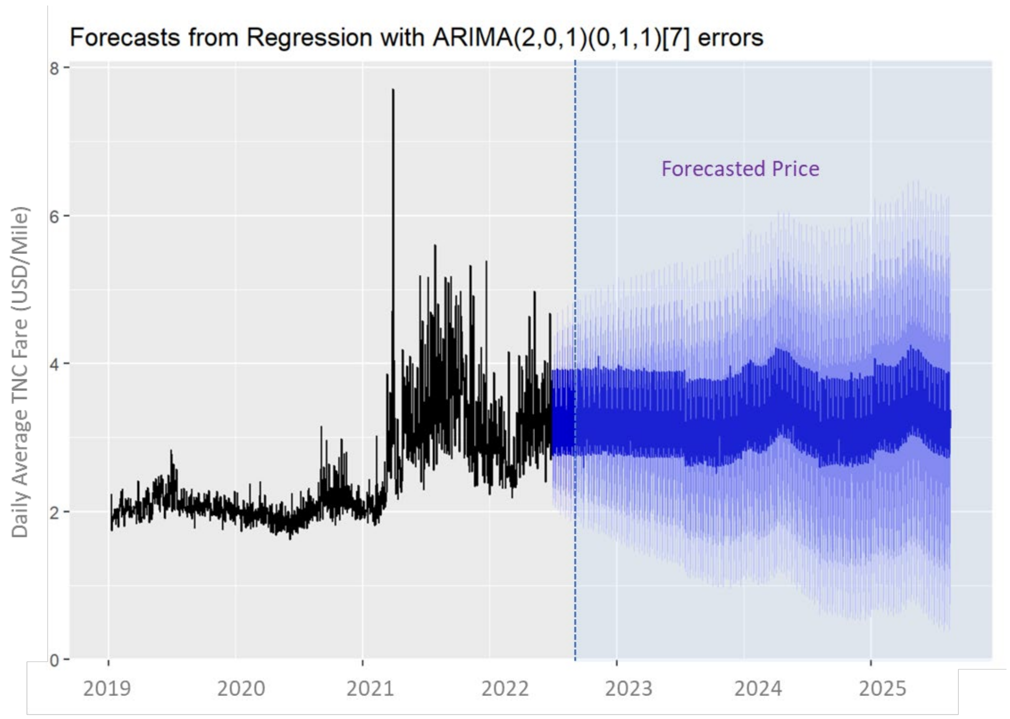

Figure 4.5 ARIMA TNC Price Forecast

4.1.3 Forecasting TNC Prices with PROPHET

The forecast with PROPHET also showed high accuracy, with an RMSE of 0.48 and a MAPE of 10.5. Figure 4.6 shows the price predictions made with PROPHET.

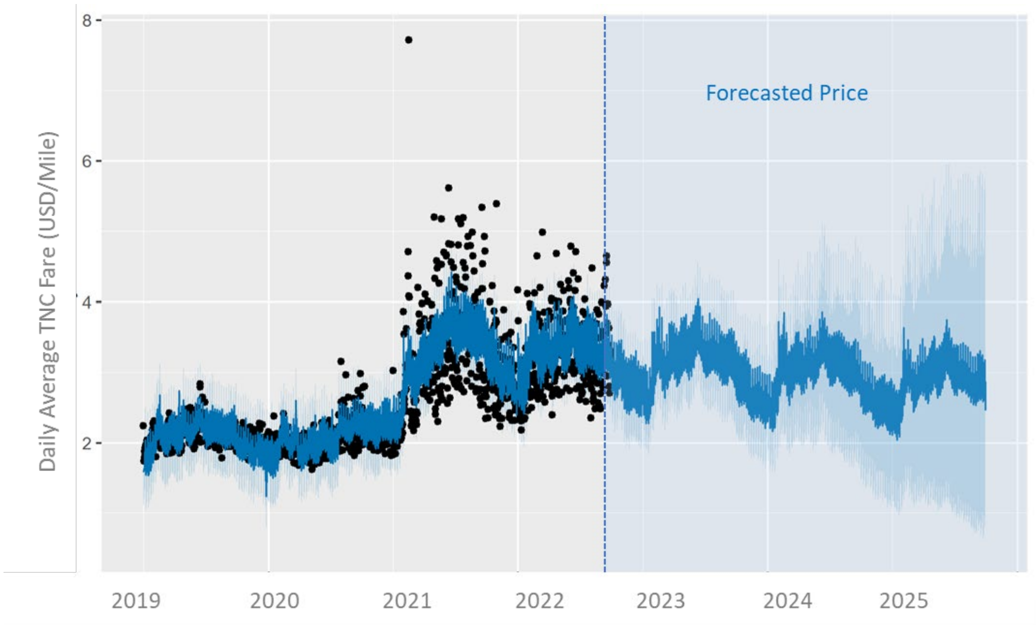

Figure 4.6 PROPHET TNC Price Forecast

Figure 4.7 shows the decomposition of the PROPHET model, reflecting the impacts of dynamic holidays, including Christmas, New Year's Eve, Independence Day, Thanksgiving, and Easter, as well as the exogenous regressors combined, including gas prices, average temperatures (TAVG), precipitation (PRCP), snow, and the lockdown.

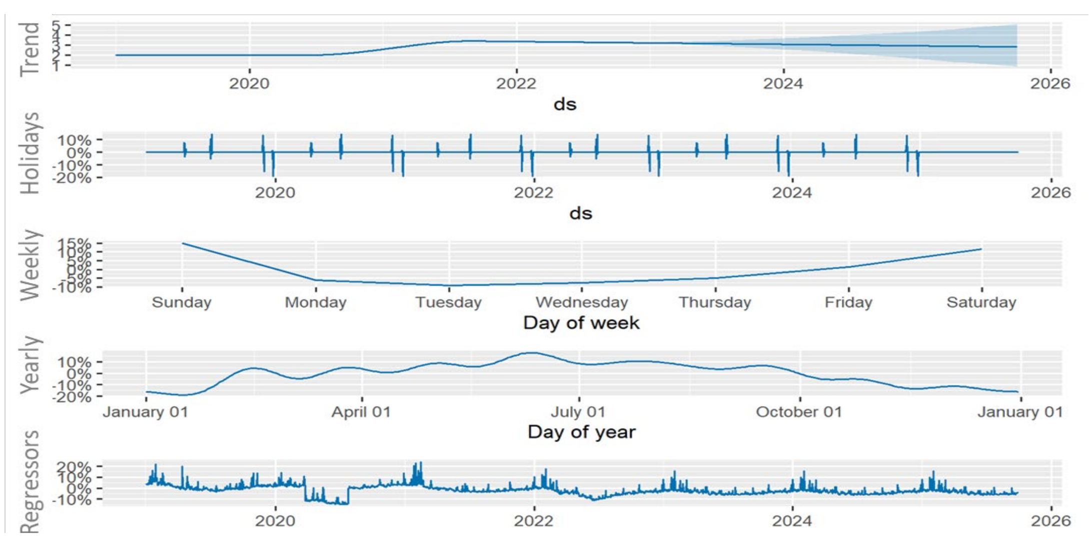

Figure 4.7 PROPHET Components

4.1.4 ARIMA and PROPHET Comparison

To further compare the forecasts from the two models, we plotted the average monthly forecasted prices. Both ARIMA and PROPHET showed that although TNC prices had decreased since their peak in 2021, there was an overall increasing trend in TNC prices starting from the outbreak of the pandemic in 2020. The average fare/mile of TNC trips, as forecasted in ARIMA, could be around \$3.23/mile throughout the upcoming three years, while the average fare/mile in 2019 was around \$2.1/mile, which was 40 percent less than the forecasted change.

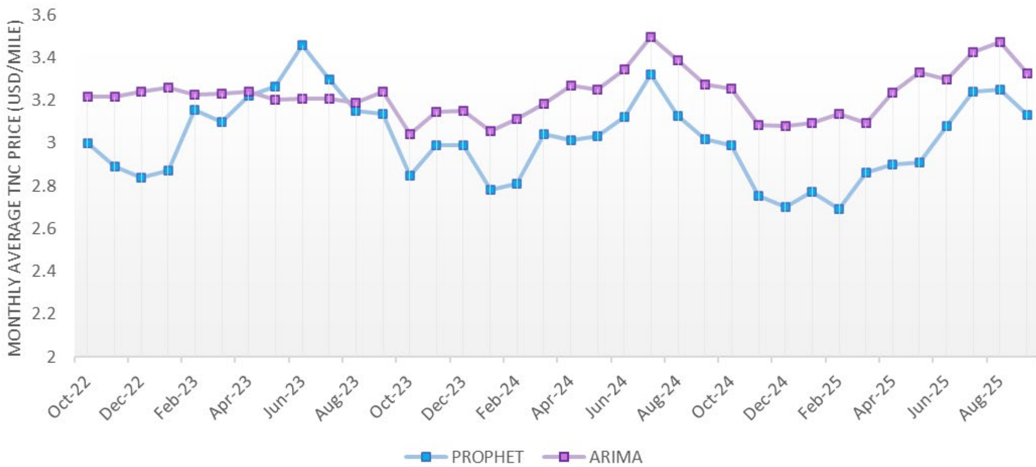

Figure 4.8 PROPHET and ARIMA Forecasted Average Monthly Price Comparison

Although ARIMA and PROPHET both resulted in comparable accuracy, when used to predict the last five months of available TNC data (May 2022 to October 2022), ARIMA performed better when we compared the RMSE, a measure of the differences between forecasted and actual values, and the MAPE (Table 4.4).

Table 4.4 Accuracy Comparison of the Two Models

	ME	RMSE	MAE	MPE	MAPE
ARIMA	0.068	0.448	0.35	0.863	10.277
PROPHET	0.186	0.48	0.368	4.122	10.593

4.2. Scenario (2): Price Increase in Response to Policy Changes

For this scenario, we tracked policy changes and regulations peculiar to the city of Seattle that had impacted TNC prices since 2019 but were not captured in the price trend extension in scenario (1). Because of the lack of available TNC trip fare data for Seattle, we tracked online and journal papers and newsletters that reported on important policy changes and the related expected or estimated percentage change in TNC prices. We found that the minimum wage ordinance and the new Seattle wage law significantly affected TNC prices, and they were predicted to keep influencing TNC prices in the coming years. Specifically, the prices for TNC trips in Seattle jumped by 25 percent in response to a new law requiring drivers to be paid the city's $16.69 per hour minimum wage in 2021 [38-40]. This minimum wage is expected to increase in the years ahead, which the city of Seattle reported would equal $18.69/hour in 2023 [41-42]. According to Uber, its 25 percent fare increase was the first of three planned increases to respond to changing policies, and its trip prices were expected to be 50 percent higher in the coming years. In this scenario, we used the reported percentage increase in Seattle's TNC prices due to local policy changes, precisely 25 percent, and combined it with the forecasted change in scenario (1). The resulting TNC price for the subsequent three years averaged about $4 per mile.

4.3. Scenario (3): TNC/Taxi Price Convergence Due to Increased Competition

For this scenario, we used available Chicago taxi trip data to compare the historical and forecasted trip prices between TNC and taxis. We used price forecasting models similar to those presented in scenario (1) to forecast future taxi prices. We chose the results from the ARIMA forecast because they produced higher accuracy in comparing price trends for taxi and TNC services in the upcoming three years.

In 2019, the average TNC trip fare per mile was $2.1, which at that time was only 37 percent of the average taxi fare/mile of $5.6. The gap was around $3.5 per mile. With a 57 percent increase in TNC prices and 25 percent decrease in taxi prices, as forecasted for 2023, this gap would significantly decrease to only $1.17, as illustrated in Figure 4.9. These converging trends in price would continue with increased competition between TNCs and taxis, which could result in TNCs pricing their trips comparably to taxis. Hence, we assumed that TNC prices would be subject to an additional 50 percent increase in this scenario, and we applied them to the average daily price resulting from the forecast in scenario (1) for 2023 to 2025.

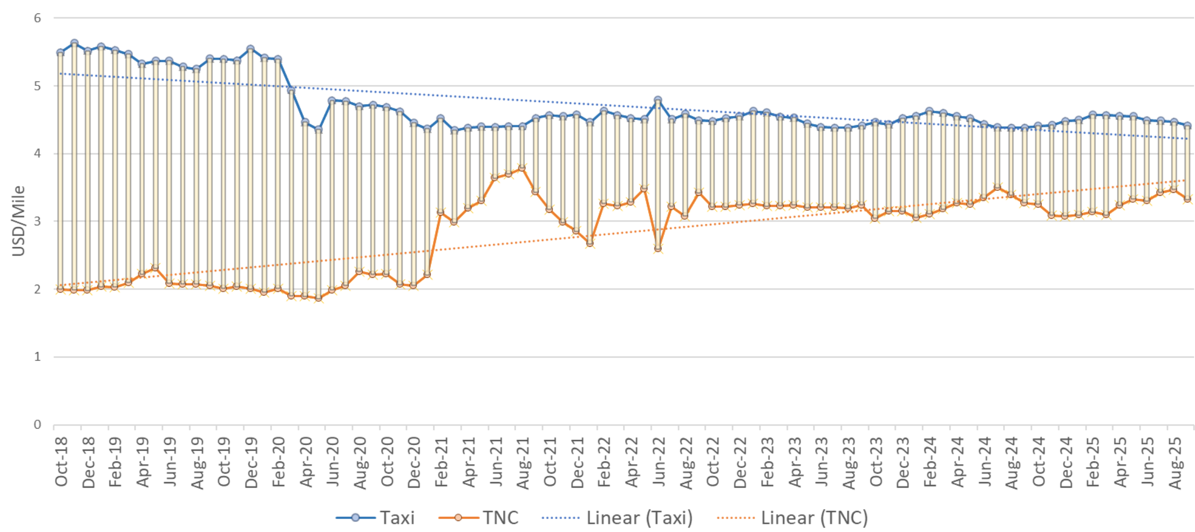

Figure 4.9 Taxi and TNC Price Comparison: Existing and Forecasted

4.4. Assessing Likely Impacts on Transit Agency-TNC Partnerships

This analysis measured the extent to which TNCs can supplement SDS paratransit trips (diversion) under each of the three TNC price change scenarios and compared the results to initial estimates of trip diversion based on 2019 TNC prices [19]. We assumed that the total annual number of ADA trips (i.e., the total demand for ADA service) in the years 2023 to 2025 would stay the same as in 2019, and we applied a fixed subsidy amount of $40 per TNC trip (determined by the transit agency KCM) to estimate the number of trips that this subsidy would cover under each of the following scenarios:

- **Scenario (1).** Price trend extension: 40 percent increase in TNC prices in comparison to those of 2019.
- **Scenario (2).** Price increase in response to policy changes: additional 25 percent increase in TNC prices on top of the price trend extension forecasted for the first scenario.
- **Scenario (3).** TNC/taxi price convergence due to increased competition: an additional 50 percent increase in TNC prices on top of the price trend extension forecasted for the first scenario.

In 2019, KCM's Access paratransit delivered 645,668 paratransit trips, 70 percent of which were 10 miles or less and hence can be considered divertible from Access to TNCs at the specified subsidy of $40 per TNC trip. At the same level of subsidy, and assuming that the total annual demand for paratransit trips remained constant for 2023 to 2025, we measured the change in divertible trips for every price change scenario. Table 4.4 summarizes the main results and the percentage of divertible trips for each scenario. The first column shows the estimated price per mile for TNC trips in 2019, the corresponding number of miles the $40 subsidy per trip covered, and the number and percentage of divertible trips. The second column, Scenario (1), shows the price per mile by applying the forecasted 40 percent increase in TNC prices. This would result in a reduction of the divertible trip rate from 70 percent in 2019 to 55 percent. The third column, Scenario (2), shows an additional price increase resulting from policy changes, which would drop the divertible trip rate to 51 percent. Finally, the fourth column, Scenario (3), shows the expected price per mile if forecasted TNC prices became similar to those of taxis, which would decrease the divertible trip rate to 45 percent.

Table 4.5 Summary of Price Change Scenarios and Resulting SDS Divertible Trips per Year

	2019	**Scenario (1)**	**Scenario (2)**	**Scenario (3)**
	No change baseline	**Price Forecast** (Time-series)	**Policy change** (Seattle region)	**Increased competition**
% Price Change Compared to 2019	**0%**	**+ 40%**	**+ 40%** **+ 25%**	**+ 40%** **+ 50%**
Price (USD/Mile)	$4.0	$5.6	$7.0	$8.4
Estimated Trip length (Miles/$40)	10 Miles	7.15 Miles	5.7 Miles	4.7 Miles
Divertible trips	450,212	353,060	330,981	289,287
% Divertible trips	**70%**	**55%**	**51%**	**45%**

CHAPTER 5. CONCLUSION

Since their entrance into the market in 2010, TNCs have been widely recognized as disruptive innovators that have significantly affected the taxi market. Although both TNCs and taxis provide similar services, TNCs' business models allow them to control their service pricing and information flow between drivers and riders. In addition, TNCs are based on market deregulation and benefit from many preemption laws. Although TNCs' business models increase their competitive advantage over taxis, they face serious profitability challenges. These are mainly a result of increased competition due to the ease of market entry, which has caused TNCs to lower their trip prices and sometimes even charge below-cost rates to price competitors out of the market.

Moreover, TNCs have been under extensive regulatory pressure, facing many legal struggles worldwide. More recently, many cities have implemented regulations to limit work hours by drivers (e.g., New York City) and influence prices to meet the minimum living wage (e.g., Seattle) [29]. As many cities continue to regulate TNCs with taxes and driver limits, TNC prices will continue to increase and may eventually reach as the level of taxi prices.

This project explored three TNC price change scenarios based on (1) price trend extension, (2) price change in response to policy changes, and (3) price convergence with taxis under increased competition. We used two different time series models, namely ARIMA and PROPHET, to forecast price changes within the next three years (2022 to 2025) based on Chicago TNC and taxi trip data. We assessed the impacts of the scenarios on potential price changes related to transit agency-TNC partnerships, using Access paratransit operated by the primary transit agency in the Seattle region as an example.

For Scenario (1), forecasting TNC price changes in the upcoming three years (October 2022 to October 2025) showed that the daily average fare per mile could increase to 40 percent higher than pre-pandemic rates. The forecasted percentage increase in average TNC fare per mile could also be higher in some cities because of local policy changes. Estimates for Scenario (2) resulted in TNC prices increasing by an additional minimum of 25 percent in response to recent changes in the minimum wage law in Seattle. As a result, TNC prices might average $7 per mile. In Scenario (3), based on our forecast for TNC and taxi prices in the upcoming three years, TNC prices could increase by an additional 50 percent and converge with taxi prices, reaching up to $8.4 per mile in Seattle.

Our findings about future TNC price increases mean that the effectiveness of transit agency-TNC partnerships is in jeopardy. In the case of Access paratransit, the cost-effectiveness of the planned pilot project would decrease substantially in any of the future scenarios. The trip diversion rate would be expected to drop from 70 percent to 55 percent, 51 percent, and 45 percent for the three scenarios, respectively.

Gas prices and inflation could have a significant impact on these findings. As gas prices increase, the operating costs for both TNCs and taxis will also increase, which may result in higher prices for customers. This could affect the price changes forecasted in the study, potentially leading to even higher price increases than those initially estimated. Additionally, inflation could also affect the forecasted price changes by increasing the cost of living, which could result in a higher minimum wage and other policy changes that would affect TNC pricing. However, price increases due to gas prices or inflation would also be likely to affect transit agencies' costs, and therefore the subsidy they provide for these partnerships would likely be adjusted to reflect these changes. Furthermore, the study acknowledges that TNCs face profitability challenges due to the ease of market entry and increased competition, which could drive them to lower their prices. If gas prices and inflation increased the operating costs for

TNCs, this could exacerbate these profitability challenges, potentially leading to increased pressure on TNCs to keep their prices low in the short term. This could affect the price forecasts, especially for scenarios in which TNC prices are expected to converge with taxi prices.

Although partnerships with TNCs could still provide many benefits, transportation planners and policymakers should carefully examine significant barriers likely resulting from TNC business models and the political environment and should design their partnerships with TNCs accordingly. In addition, transit agencies should start to explore longer-term service innovations in anticipation of new transportation technologies, such as electric vehicles and autonomous vehicles, which could have significant implications for TNC business models and prices.

This research has some limitations. An obvious shortcoming is that the price changes were estimated on the basis of average USD/mile trends in Chicago and then were applied to Seattle, but the two cities may not follow identical trends. Another limitation is the unavailability of data pertaining to TNCs' promotional discounts, traffic, and the number of available drivers, which affect trip prices but were not included in the model. Because the city of Chicago started to regulate surge pricing in certain areas, including downtown, adding a regressor based on geography could improve the accuracy of the forecast. That said, it will be challenging to capture the impacts of these variables without any actual data to isolate the effects of surge pricing, discounts, and upfront pricing. Finally, it should be noted that the fares in the Chicago data were rounded to the nearest multiple of $2.50, reducing the precision of the estimated average fare per mile and forecasted price change.

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APPENDIX A

Taxi Price Forecasting—ARIMA Results

Using both the ARIMA and PROPHET models, we forecasted the average fare per mile for taxis within the next year (October 1, 2022 - October 1, 2025). For the ARIMA model, we used the auto ARIMA function in R to optimize the model parameters by using AIC and BIC. We obtained a SARIMAX model, which is a seasonal ARIMA with regressors, with the following parameters:

For the non-seasonal data, our model had the following parameters:

$p = 0$: Auto Regression with zero lags

$d = 1$: one differencing

$q = 3$ moving average with three lags for error.

For the seasonal data, our model had the following parameters:

$P = 2$: Auto Regression with two lags

$D = 0$: No differencing

$Q = 0$: moving average with zero lags.

We trained the model and tested it for accuracy using the last available five months of taxi prices (May 2022 to October 2022). We obtained the coefficients for the Arima model shown in Table A.1 for moving average 1, 2, and 3 and seasonal autoregression 1 and 2, followed by the coefficients for the external regressors, as shown in Table A.2.

Table A.1 ARIMA Coefficients – Taxi Price Forecast

	ma1	**ma2**	**ma3**	**sar1**	**sar2**
coef	-0.822	-0.0975	-0.0494	0.1222	0.1558
s.e.	0.177	0.0214	0.0178	0.0174	0.0173

Table A.2 External Regressors Coefficients - Taxi Price Forecast

	Christmas	**Easter**	**Thanksgiving**	**New year**	**Independence**	**Lockdown**	**PRCP**	**SNOW**	**TAVG**	**gas**
	0.0978	0.097	-0.3112	0.1593	-0.0757	-0.2542	0.1015	-0.0081	-0.0047	0.0671
s.e.	**0.1086**	0.103	0.1084	0.1084	0.1084	0.0832	0.0191	0.009	0.0006	0.0469

The SARIMAX model produced high accuracy, with an RMSE of 0.34 and a MAPE of 4.88. We used this model to predict future taxi prices for the next three years, as illustrated in Figure A.1.

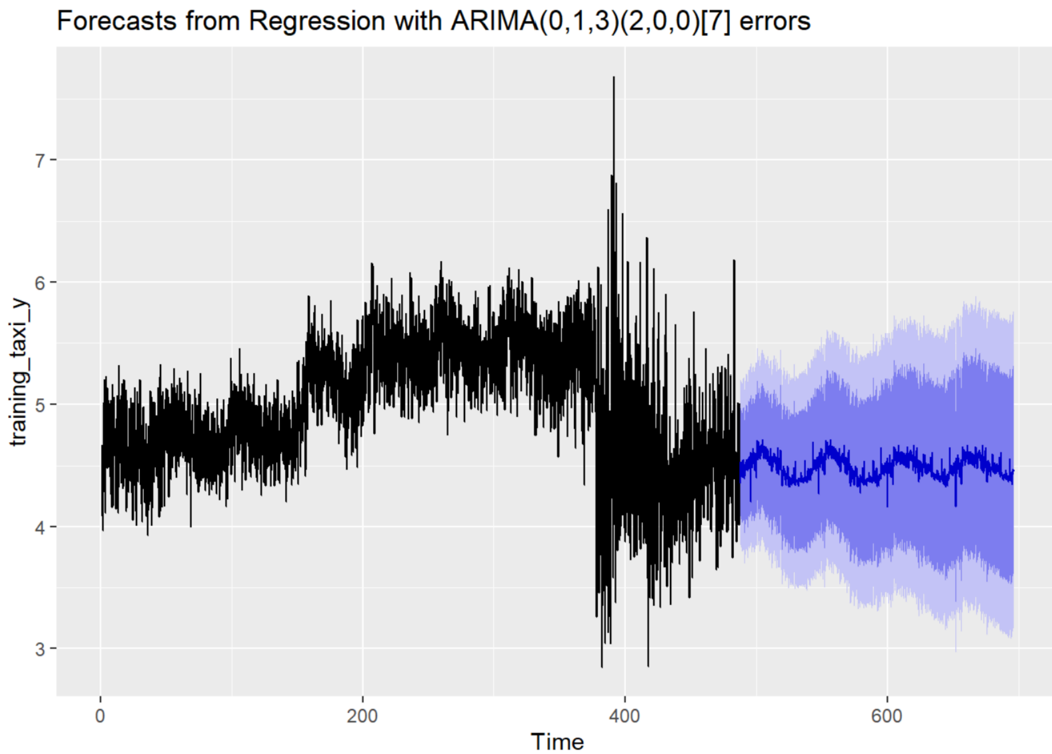

Figure A.1 ARIMA Taxi Price Forecast

Exploring the ARIMA results for exogenous regressors, which also included holidays, indicated that Thanksgiving, the lockdown, and average temperature had a statistically significant negative positive correlation with average taxi fare, whereas New Year's Eve, precipitation, and gas prices had a statistically significant correlation with average taxi fare.

Taxi Price Forecasting—PROPHET Results

The forecast with PROPHET also showed high accuracy, with an RMSE of 0.4 and a MAPE of 7.2. Figure A.1 shows the price predictions made with ARIMA, and Figure A.2 shows the price predictions made with PROPHET. Both SARIMAX and PROPHET showed that although a slight increase in taxi prices might happen at the beginning of the next year, there would be an overall decreasing trend in taxi prices. These would average around $4.5/mile throughout 2023 and then drop to an average of $4.3/mile in 2025. Figure A.2 shows the decomposition of the PROPHET model, reflecting the impact of dynamic holidays including Christmas, New Year's, Independence Day, Thanksgiving, and Easter, as well as the exogenous regressors combined, including gas prices, average temperatures (TAVG), precipitation (PRCP), snow, and the lockdown.

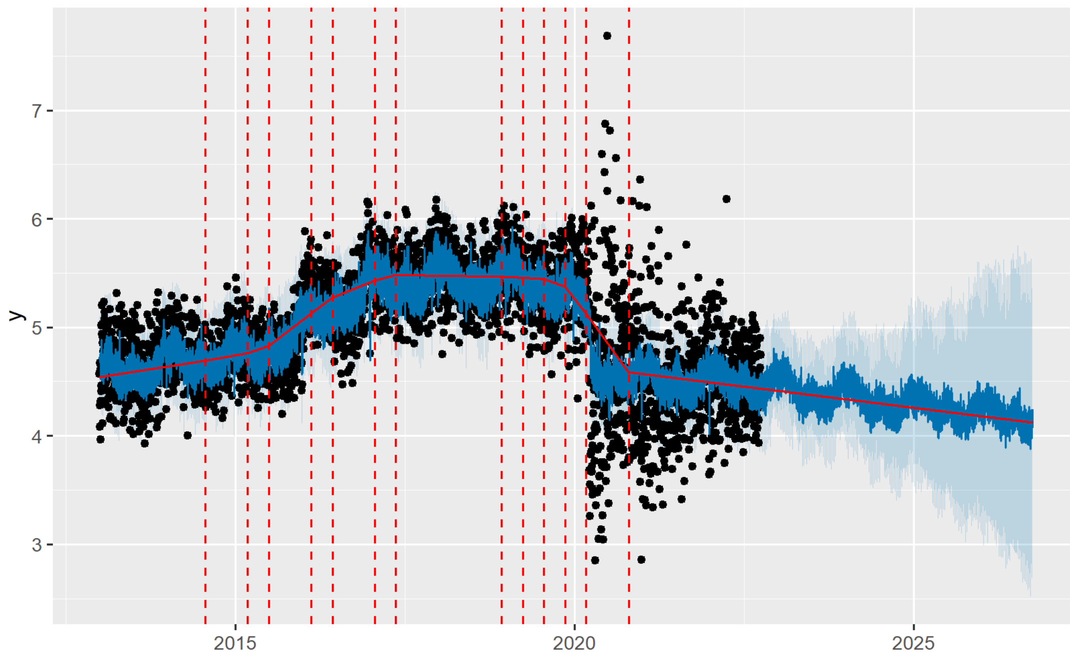

Figure A.2 PROPHET Taxi Price Forecast

By exploring the model decomposition, we can examine the impact of the previously specified holidays on prices. In Figure A.3, the holidays graph shows that New Year's Eve usually increased the average fare per mile by 2 percent, whereas the first day of the year (New Year's Day) dropped prices by over 8 percent. This can be attributed to the influx of demand after New Year's Eve celebrations. Similarly, other holidays, including Easter, Independence Day, and Thanksgiving, generally resulted in price increases. In contrast, Christmas resulted in a price decrease, especially on Christmas Day, as fewer people travel that day. The exogenous graph also shows that the lockdown resulted in a drop in prices of over 7 percent.

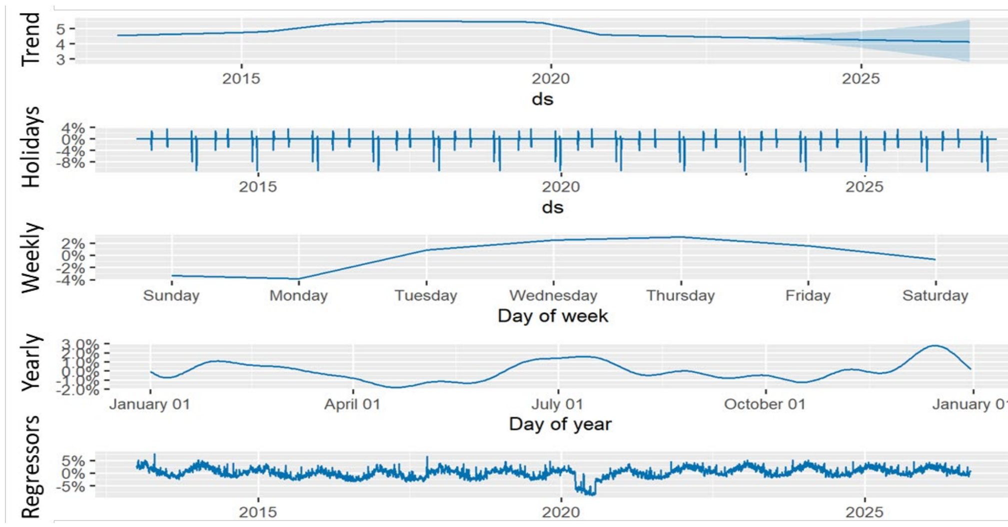

Figure A.3 PROPHET Decomposition – Taxi Price Forecast

The coefficients of the exogenous regressors suggested that the COVID-19 lockdown, which took place between March 2020 and July 2020, resulted in a decrease in price of 3 cents per mile. In contrast, with the increase in gas price per gallon (USD/gallon), TNC price per mile increased by 3 cents per mile. Weather variables, including snow, precipitation, and average temperature, generally increased prices during colder weather. For every 1 degree increase in average temperature, the TNC price per mile decreased by 1 cent, and for every inch increase in snow depth, TNC price per mile increased by 0.7 cents. Similarly, for every inch increase in precipitation, the TNC price per mile increased by 0.2 cents.